

Results of the Magnetic Properties Experiment on the Mars Pathfinder Lander.

S.F. Hviid¹, M.B. Madsen¹, J.M. Knudsen¹, H.P. Gunnlaugsson¹, W. Goetz¹, A.R. Dinesen¹, C.T. Mogensen¹, C.T. Pedersen¹ and R.B. Hargraves²

¹Ørsted Laboratory, Niels Bohr Institute for Astronomy, Physics and Geophysics, University of Copenhagen, Universitetsparken 5, DK-2100 Copenhagen Ø (stubbe@fys.ku.dk)

²Department of Geosciences, Princeton University, New Jersey, USA

Introduction

The Mars Pathfinder lander carried an instrument package called the Magnetic Properties Experiments [1]. The principal idea of the instruments is to attract airborne magnetic dust particles onto the surface of the instruments. These instruments were designed to further elucidate the nature of, and constrain the origin of, the magnetic phase known to be present in the martian fines.

The package consisted of three types of instruments; (1) two magnets arrays, (2) one tip plate magnet and (3) two ramp magnets. The instruments contain permanent magnets mounted in a way that produce a wide range of values of the magnetic field and the magnetic field gradient on the surface of the instruments [2].

The magnet arrays include 5 "bull's-eye" magnets. The magnet arrays gave a "rough" measurement of the magnetic properties of the airborne dust, and permitted a spectroscopic investigation using the onboard multispectral imager (the Imager for Mars Pathfinder (IMP) [3]).

The tip plate magnet (mounted about 7 cm from the imager) was designed to investigate the detailed patterns of dust on the surface (especially chain formation). The tip plate magnet produces a range of magnetic field gradients corresponding (approximately) to the 4 strongest magnets of the magnets arrays.

The ramp magnet is a 10x10 cm² magnet mounted at the far end of the ramps used by the Sojourner Rover to depart from the lander. These magnets were optimized to give a large signal to noise ratio when measuring the elemental composition using the Alpha Proton X-ray spectrometer (APXS) mounted on the Rover. The average magnetic field strength and field gradient of the ramp magnets are between those of magnets 3 and 4 of the magnet array.

The ability of the magnets to attract and hold dust from the atmosphere varies considerably from magnet to magnet. A rough estimate of the relative capture cross-section of the magnets may be obtained through the product $B \cdot \nabla B$ for each magnet. This gives a relative strength of 100:9:3:1:0.2. For example, if magnet 1 (the strongest) needs 50 sols to saturate, magnet 2 would need about 550 days to saturate, assuming a constant amount of dust in the martian atmosphere. The capture of magnetic particles is a complicated process that depends on several parameters.

Results

On the magnet arrays the following development was observed: By sol 5 a faint bull's-eye pattern (testifying to adhering particles) could be seen on the strongest magnet (#1), of the arrays. With time this pattern has strengthened and patterns have successively appeared on magnet 2 (sol 10)

and magnet 3 (sol 21). On sol 34 a faint pattern was present also on magnet 4. On sol 63 a week pattern that may be a bull's-eye pattern was observed on magnet 5. Figure 2 shows the upper and the lower magnet arrays on sol 80.

Fine dust has slowly settled on all the exposed surfaces of the lander and rover. However, detailed analysis of the magnet images has shown that a relatively clear "halo" surrounds the strongest bull's-eye magnet. This magnet appears to some degree to have cleansed its immediate surroundings of settled dust. This result suggests that a major fraction rather than only a small percentage of the particles is magnetic, otherwise the prevailing level of dust cover would be present.

The tip plate magnet shows a clear asymmetric pattern. The tip plate magnet is basically a distorted "bull's-eye" magnet, where the variance of the magnetic field is produced by tilting the magnet relative to the surface. Figure 2 shows that the dust has accumulated around the whole circular part of the magnet. This means that dust is sticking also to the part of the magnet where the magnetic field gradient is weakest. This is in correspondence with dust sticking to magnet 4 of the magnet arrays. The dust pattern does not show any signs of chain formation. Figure 1 shows the tip plate magnet as seen on sol 78.

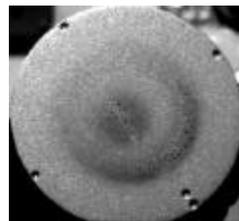


Figure 1. The tip plate magnet as observed on sol 78. The tip plate magnet is mounted about 7 cm from the right eye of the lander camera.

The only result obtained from the ramp magnet is the fact that dust is indeed sticking to the magnet. Unfortunately, the mission came to an end before the Rover could return to the ramps to obtain an APX-spectrum of the magnetic separate on the ramp magnet. Figure 3 shows the rear ramp magnet with a faint reddish sheen indicating a layer of dust.

Based on model simulations and Mars sample analogue investigations, we interpret the magnet array results as follows: The fact that four (perhaps five) of the magnets have captured dust during the mission, requires that the collected particles have an average saturation magnetization (σ_s) of about 4 Am²/kg. From this we conclude that macroscopic hematite ($\sigma = 0.4$ Am²/kg) can not be responsible for the magnetization of the airborne dust. This does not mean that hematite can not be present in the suspended grains; rather that it cannot account for the results of the magnetic properties experiments. However, the weaker magnets may well be culling a subset of dust that has a much higher saturation

magnetization than the average. Laboratory simulation experiments indicate that the material on magnet 4 may have a value of saturation magnetization as high as about $\sigma_s = 20 \text{ Am}^2/\text{kg}$ [4].

Discussion

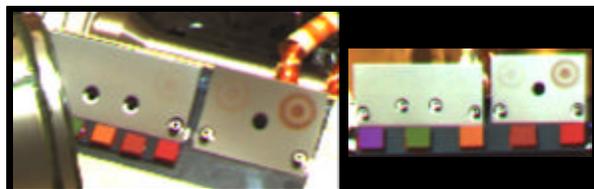
There is spectral evidence of ferric iron in the martian soil. Furthermore, the soil in general is not only highly oxidized, but also strongly oxidizing. Taking into account that the particles suspended in the atmosphere are small ($< 2 \mu\text{m}$), we doubt that native iron or pyrrhotite can possibly be present. Magnetite (Fe_3O_4 , contains Fe^{2+}) is also doubtful as a component of the dust. These arguments favor the interpretation that the mineral causing the magnetism in the dust on Mars is predominantly maghemite ($\gamma\text{-Fe}_2\text{O}_3$).

Next to magnetite, maghemite has the highest spontaneous magnetization ($\sigma_s \approx 70 \text{ Am}^2/\text{kg}$) known among the ferri-magnetic oxides. If the particles are mostly composite, maghemite seems to be the most likely candidate for the magnetic component. If this is true, then to have an average saturation magnetization of about $4 \text{ Am}^2/\text{kg}$, about one third of the Fe_2O_3 known to be present in the martian soil must be in the form of maghemite. In this case more than one iron-containing mineral must be present in the soil. A less probable possibility for the magnetic phase in the composite particles, is the mineral ferroxhyte, $\delta\text{-FeOOH}$ ($\sigma_s \approx 15 \text{ Am}^2/\text{kg}$), but in this case nearly all the ferric iron in the martian fines must be in this form. No other known forms of crystalline ferric oxide or oxyhydroxide are sufficiently magnetic to yield the results obtained. Nanophase ferric oxide (nanophase hematite) has previously been postulated to be sufficiently magnetic to satisfy the results, but recent laboratory experiment makes this possibility unlikely.

The bulk composition of the martian dust requires the presence of silicates. One possible interpretation is that the maghemite is present as a component of composite silicate-ferric oxide (clay-ferric oxide) particles which constitute the bulk of the martian soil and dust.

There are several possible pathways to the formation of a magnetic phase in the soil.

Titanomagnetite could be inherited from the underlying bedrock e.g. via comminution or weathering. On the surface of Mars the titanomagnetite might be oxidized to titanomaghemite. Alternatively, interaction of hot basaltic magma with ground ice or water is known to produce the mineraloid called palagonite which often contains small amounts of titanomagnetite or titanomaghemite.



Figur 2. (left) The upper and (right) the lower magnet array as imaged on sol 80.

If these phases are responsible for the magnetic properties of the soil, then the magnetic phase in the soil will have a different concentration of titanium than in the soil in general.

The pathway for formation of aggregates consisting of clay minerals cemented or stained by iron oxides and oxyhydroxides is not obvious. The rocks around Pathfinder seem comparatively unweathered. Furthermore, presently liquid water is not stable anywhere on the planet. This situation has probably prevailed since at least the end of the terminal bombardment. Liquid water has episodically emerged at the surface; however, to catastrophically carve the outflow channels and more slowly erode the valley networks. These emissions were most likely caused by impacts and/or igneous-induced hydrothermal activity. Such water would carry in solution ions leached from the bedrock during its long subsurface residence. Upon emerging at the surface, precipitation/freezing/sublimation must inevitably have occurred.

Conclusions

The particles suspended in the martian atmosphere are composite and they contain a magnetic phase. We favor the interpretation that the magnetic mineral in the particles is predominantly maghemite occurring as a staining on clay-like minerals or as a cementing mineral in clay aggregates. We propose that the martian soil is largely composed of such particles and that these particles are freeze-dried precipitates from ground water, which emerged at the surface.

The possibility remains, however, that the magnetic particles are titanomaghemite occurring in palagonite-like material. The titanomaghemite is then – via oxidation – inherited directly from the basaltic bedrock. In this case the iron has not been present as free ions in liquid water.

None of these alternatives can be unequivocally chosen based solely on the magnetic properties experiments, especially since the mission came to an end before the APX measurement could be performed on the ramp magnet.



Figur 3. The rear ramp magnet.

- [1] S.F. Hviid et al., *Science* 278, 1768-1770, 1997. [2] H.P. Gunnlaugsson et al., *Space Sci.* (in print). [3] P. Smith et al., *J. Geophys. Res.* 102, 4003-4025, 1997. [4] C.T. Pedersen et al., *LPSC-98*